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VALIDATION OF THE TRUCK/SHOVEL SIMULATION MODEL

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VALIDATION OF THE TRUCK/SHOVEL SIMULATION MODEL

by

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ABSTRACT

A loading and hauling equipment simulation model vas developed to satisfy the requirements and need of the mining industry in western Canada. It is expected the model will be used to determine the impact of various combinations of loading and hauling equipment, company policies and maintenance procedures, haulage requirements, to evaluate possibilities of the use of truck monitoring and dispatch systems, and to assess loading and hauling equipment productivities.

To evaluate the model and to assess its capabilities in addressing the above requirements, the model vas validated. The validation vas based on the following:

1. Running the model in-house to evaluate its structure,
2. Running a "test case" by using models developed elsewhere to compare the results of simulation,
3. Soliciting of model critiques from outside agencies, and
4. Comparison of calculated data with real time study data.

The presented paper provides an overviev of the validation processes and summarizes results obtained during comparison and evaluation studies.

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VALIDATION DU MODÈLE DE SIMULATION DE CAMIONS/PELLETEUSES

par

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RÉSUMÉ

On a élaboré un modèle de simulation du matériel de chargement et transport, pour satisfaire aux exigences et aux besoins de l'industrie minière de l'ouest du Canada. On prévoit d'utiliser le modèle pour déterminer l'impact des diverses combinaisons de matériel de chargement et de transport, des principes directeurs des compagnies et des procédés d'entretien, des exigences en matière de transport, de façon à évaluer les possibilités d'utilisation des systèmes de surveillance et d'expédition des camions, et pour évaluer la productivité du matériel de chargement et de transport.

Pour évaluer le modèle et sa capacité à couvrir les exigences susmentionnées, on a validé ce modèle. La validation était basée sur les détails suivants :

1. La mise à l'épreuve du modèle sur place, pour évaluer sa structure,
2. La mise à l'épreuve d'un "cas expérimental", au cours de laquelle on a utilisé des modèles élaborés ailleurs pour comparer les résultats de la simulation,

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3. La demande de critiques des modèles, qui soient formulées par des organismes de l'extérieur et
4. La comparaison des résultats de calculs aux données fournies par les études en temps réel.

Dans cet article, on donne un aperçu des procédés de validation, et l'on résume les résultats obtenus durant les études de comparaison et d'évaluation.

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INTRODUCTION

The loading and hauling equipment simulation model was developed by the System Laboratory of the National Research Council in Ottawa to satisfy the requirements and need of the mining industry in western Canada and is expected to be used mainly for the following purposes:

- to determine the impact of various types of loaders, maintenance strategies, size of reserve fleet, road layout and maintenance, speed limit, tire selection, and company policies on productivity and operating costs of the truck fleet,
- to evaluate possibilities of the use of truck monitoring and dispatch systems and the advantages of using such systems, and
- to assess loading and hauling equipment productivities.

To evaluate the model and to assess its capabilities in addresing the above named requirements, the model was validated. The validation of this model was based on the following:

1. Running the model in-house to evaluate its general structure.

   In-house evaluation resulted in upgraded versions of the model and in improved performance of the model. This is a continuous process. It is expected that new developments and modifications to the model will continue.

2. Running a "test case" by using models developed elsewhere to compare the results of simulation with the results of the in-house model.

   Truck manufacturing companies (Caterpillar, Wabco, Euclid, Terex, Kress, Unit Rig, and Komatsu) were asked to run the "test case" of mine haulage simulation using their computer program. The results were evaluated and compared with the data output from the in-house model, using similar input data.

3. Soliciting of the in-house model critiques from mining companies.

   A copy of the model with "User's manual" was lent to several mining companies for their evaluation and comment. Formal presentation of the in-house model was made to invited mining engineers and computer programmers and their comments were incorporated in the program. Presentations to selected mining companies were made using actual field data collected from the mines previously, so that each company was able to witness simulations of their own haulage operations.

4. Comparison of calculated data with actual time study data collected in field.

   Time studies were done at selected mine sites and the collected data were compared side by side with the data provided by the computer simulation.

In this paper, an overview of the validation studies is presented and data acquired from others or during field time studies, summarized. The length limitation on this paper does not allow for all results to be listed here. Instead, summaries of data needed for comparison with the results of in-house studies, are provided.

here. Instead, summaries of data needed for comparison with the results of in-house studies, are provided.

The data received from manufacturers and data calculated in-house are listed in the paper followed by time study data. The comparison and evaluation of the sets of data, and critique of the model by users conclude this paper.

APPLICATION STUDIES

A section of mine haulage road was selected from Highvale mine, Alberta to be the test case in the validation experiment. The sketch of the area under consideration is shown on Fig. 1.

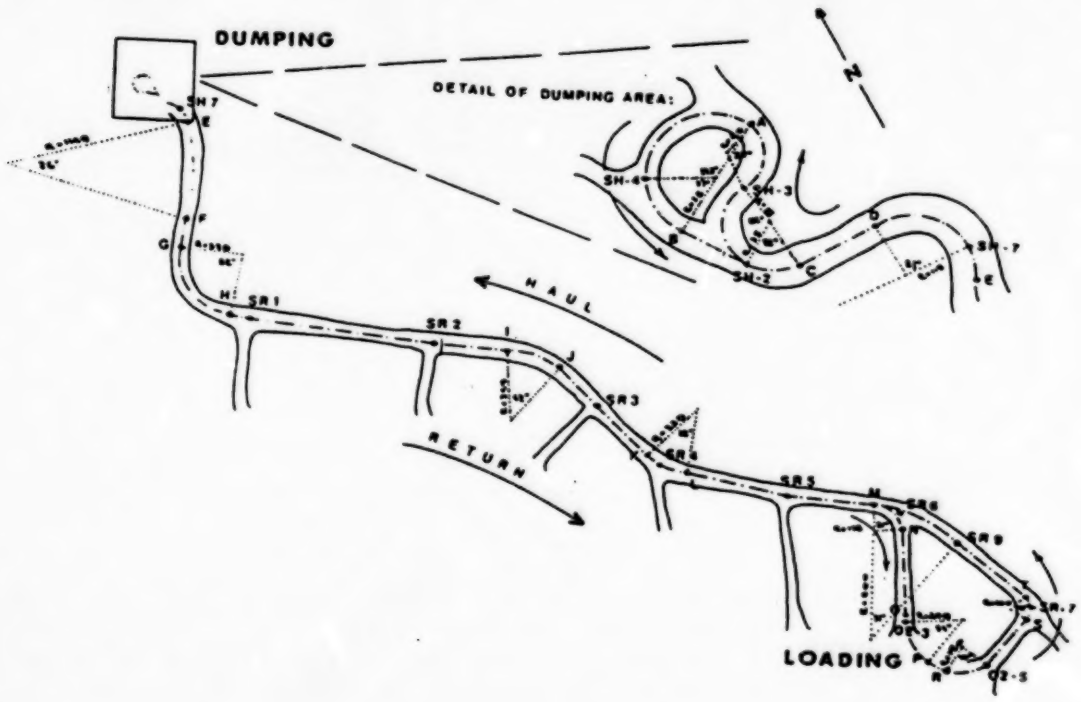

Figure 1 Test Case Haulage Network.

The loading and hauling logic is as follows:

The truck is loaded in Pit 02-S at Point 02-5 and starts to move up the ramp to point SR-7 located on the main haulage road. The truck continues on the main haul road to the Sundance power plant dumping area. Details of the dumping area are shown on the Figure. The load is dumped at Point SH-3 and the return portion of the trip follows the road by points SH-4

and SH-2. There are two areas of one way traffic, both anticlockwise: one at the loading area, the other at the dumping area.

A letter describing the requirements of the test case study and giving all the necessary data, was mailed to selected truck manufacturers. The truck manufacturers were requested to select from the fleet of company's vehicles one that may be tested to run over the test profile. Time and fuel consumption over each seqment and in total for empty and loaded trucks and for the whole cycle were expected to be calculated. Production per hour and shift for each type of selected truck, average load on tires, TKPH ratings and average speed were also required. Ownership and operating cost were proposed to be calculated using data supplied and used by the company on similar studies.

All of the companies that responded were later visited and the test case run using their computer program. Only one company, Caterpillar, provided a copy of their program to be installed and used in-house.

Data, that were compared in the study included hauling and return times, loading and dumping times, and load site moves. Not all companies provided this information in the order suggested, therefore adjustment in their values was made to standardize the data. Some companies have a computer program that include queuing times averages in their hauling or return times. This value could be identified in the program printout by deducting the travel times, or total stay on the road time from the time shown as hauling or return time in the calculation.

Data provided by the manufacturers were summarized and compared with data calculated by using the developed simulation model. The data calculated by various manufacturers and data calculated by using in-house developed computer model are summarized in Table 1.

Table 1 Summary of Calculated Data

	MANUFACTURERS AND SML DATA													
	TEST 1		TEST 2		TEST 3		TEST 4		TEST 5		TEST 6		TEST 7	
UNITS	KRESS	SML	WABCO	SML	EUCLID	SML	TEREX	SML	CAT	SML	UNIT RIG	SML	KOMATSU	SML
TRIPS/OPER.HR	2.46	2.46	2.43	2.44	2.11	2.13	2.82	2.82	2.93	3.11	1.56	2.61	2.79	2.98
PRODUCTION: [t/hr]	371.88	362.64	275.73	281.57	121.95	157.54	169.96	177.78	133.72	130.65	158.86	164.85	173.51	187.75
FUEL CONSUMPTION:														
[l/hr]	121.44	120.44	106.69	112.02	53.02	52.52	N/A	90.10	N/A	83.41	61.73	104.87	N/A	97.54
[l/t]	0.326	0.331	0.387	0.398	0.435	0.447		0.507		0.638	0.453	0.636		0.519

FIELD TIME STUDIES

The Highvale mine near Wabamum in Alberta was selected for time study of the mining operation. All trucks operating at the mine during the survey were monitored. The mine was using mostly Kress trucks on the run selected later as the test case, therefore values included in this validation study are for Kress trucks only. Other truck times are evaluated elsewhere (Srajer, 1985 a, 1985 b, 1985 c).

The truck times were measured between Pit 02-S and the Sundance Power Plant and Pit 02-S and the Keephills Power Plant. Measured times were summarized and mean values calculated. These values are summarized in Table 2 for loaded and empty trucks.

Table 2 Summary of Mean Times

Loaded trucks:			
Section	Mean time (sec.)	Std. dev.	Units of obs.
SR-7 - SR-9	27.57	2.27	30
SR-9 - SR-6	25.26	2.09	38
SR-3 - SR-2	53.95	2.80	37
SR-2 - SR-1	68.62	2.99	37
SR-1 - SH-7	79.52	2.41	48
SH-2 - SH-3	9.00	1.26	38
Empty trucks:			
Section	Mean time (sec.)	Std. dev.	Units of obs.
SR-3 - SR-2	47.42	1.68	38
SR-2 - SR-1	50.12	2.79	43
SR-1 - SH-7	70.85	1.57	40
SH-4 - SH-2	7.30	0.90	40
SH-3 - SH-4	18.17	1.07	46

Using the measured distance between the control points and mean time, velocities in [km/h] were calculated for each segment. The mean velocities are as in Table 3.

The loaded and empty truck velocities were calculated in order to establish "comparable" data with time values from the manufacturers and in-house simulation study. The TKPH value limit was not imposed during the calculation of maximum speed for each segment of haulage run, because times measured in the field were close to the mine speed limit of 67 km/h for empty and 60 km/h for loaded trucks. If the TKPH limit was imposed during the computer simulation, calculated values would not be comparable at all. The adjusted values were therefore established for comparison study, using time weighted averages for each segment.

The comparison of the values used for validation of the model is included in the following section of the paper.

Table 3 Summary of Mean Velocities

Loaded trucks:			
Section	Mean vel. (km/h)	Std. dev.	Units of obs.
SR-7 - SR-9	68.42	6.19	30
SR-9 - SR-6	60.25	4.91	38
SR-3 - SR-2	60.22	3.17	37
SR-2 - SR-1	23.65	1.10	37
SR-1 - SH-7	59.81	1.83	48
SH-2 - SH-3	32.63	4.54	38
Empty trucks:			
Section	Mean vel. (km/h)	Std. dev.	Units of obs.
SR-3 - SR-2	68.1	2.40	38
SR-2 - SR-1	68.3	3.93	43
SR-1 - SH-7	67.10	1.52	40
SH-4 - SH-2	50.15	6.95	40
SH-3 - SH-4	22.86	1.42	46

COMPARISON OF DATA

Data from the study were summarized in Table 4 to provide an overview of data from in-house computer model, here called "Base case", and data supplied by truck manufacturers.

The following units were compared:
1. Trips/hour,
2. Production/operating hour,
3. Fuel consumption [l/cycle], and
4. Fuel consumption [l/t].

Table 4 Comparison of Base Case and Manufacturers Data

COMPARED UNIT		DIFFERENCES FROM BASE CASE													
		KRESS		WABCO		EUCLID		TEREX		CATERPILLAR		UNIT RIG		KORATSU	
		BASE	COMP.	BASE	COMP.	BASE	COMP.	BASE	COMP.	BASE	COMP.	BASE	COMP.	BASE	COMP.
TRIPS/HOUR	-	2.46	2.46	2.44	2.43	2.13	2.11	2.82	2.82	3.11	2.93	2.61	1.56	2.98	2.78
	%	0		0.41		-0.94		0		-5.19		-40.23		-6.38	
PRODUCT/OPER. HR	t/h	311	319	241	236	101	105	152	146	112	115	141	136	161	149
	%	+2.55		-2.08		+3.75		-4.40		+2.35		-3.63		-7.59	
FUEL CONS./(/cycle)		48.9	49.4	45.9	43.9	24.7	25.1	31.9	----	26.8	---	40.2	39.6	32.7	---
	%	+1.00		-4.38		+1.90		------		-------		-1.52		-------	
FUEL CONS./(/t)		0.331	0.326	.398	.387	.447	.435	.507	----	.638	----	.636	.453	.519	----
	%	-1.51		-2.76		-2.69		-----		------		-28.77		-------	

The base case was compared with data from each manufacturer separately and the percentage difference from the base case was calculated. Average differences from base case, in absolute value, were summarized as follows:

Trips/hour : 2.25 %,
Production/op. hour : 3.40 %,
Fuel consumption [l/cycle] : 2.20 %,
Fuel consumption [l/t] : 2.32 %.

The extreme values calculated by Unit Rig for trips/hour [-40.23 %] and fuel consumption in l/t [- 28.77] were not included in the evaluation. These values were impossible to adjust in a comparison study, because the company did not provide any background information for the calculation.

With the above noted exception, data from the base case are comparable to the data provided by the manufacturers.

In Table 5 the data supplied by Kress are compared with "base study" data and time study data.

Table 5 Measured Time Data

MEASURED TIME DATA (SEC.)						
SEGMENT	LOADED TRUCKS			EMPTY TRUCKS		
	FIELD	KRESS	BASE STUDY	FIELD	KRESS	BASE STUDY
SR7-SR9	27.6	30.9	31.2	----	--------	--------
SR9-SR6	25.3	25.5	25.8			
SR3-SR2	54.0	59.6	60.0	47.4	43.7	43.8
SR2-SR1	68.6	61.6	63.0	50.1	46.4	46.2
SR1-SH7	79.5	72.8	72.6	70.8	63.8	63.6
SH4-SH2	----	----	----	7.3	6.2	6.6
SH2-SH3	9.0	8.0	7.8	----	-----	-----
SH3-SH4	----	---	----	18.2	13.4	13.2

The differences [in %] between time study data and Kress calculated data with the base case are listed in Table 6. In this table, the Kress adjusted data are very close to the base study data. The data from actual time study compare closely with the data from the base case, if speed limit by TKPH values is not imposed in the calculation. The speed of Kress trucks was closer to the maximum speed limit imposed by the mine and used in the base case calculation. The extreme values in the time study were investigated and explained (Srajer, 1987).

Remaining values are within 10 % of the base case values. This was considered acceptable for this comparison study. Generally, loaded trucks

run slightly "slover" at the mine than as calculated by the model while empty trucks are 15 % "slover" than calculated.

Table 6 Time Study and Manufacturers Data Comparison

SEGMENT	DIFFERENCES FROM BASE CASE (%)			
	LOADED TRUCKS		EMPTY TRUCKS	
	TIME STUDY	KRESS STUDY	TIME STUDY	KRESS STUDY
SR7 - SR9	-11.54	-0.97	-------	----------
SR9 - SR6	- 1.94	-1.17	-------	----------
SR3 - SR2	-10.00	-0.67	+ 8.22	+0.23
SR2 - SR1	+ 8.89	-2.22	+ 8.44	+0.43
SR1 - SH7	+ 9.50	+0.27	+11.32	+0.31
SH4 - SH2	------	-----	+10.61	-6.06
SH2 - SH3	+15.38	+2.56	------	-------
SH3 - SH4	------	-----	+37.88	+1.52

CONCLUSION

The computer model defined and validated was accepted as a useful tool by various mining companies. The model was validated using data collected in the field. A test case was also run by various truck manufacturers, using their equipment computer model.

In summary:

1. **Application studies**

A test case (set of the haulage segments from Pit 2S to the Sundance Power Plant at Highvale mine) was sent to seven truck manufacturing companies to be evaluated using their computer models. The results were summarized and compared with similar case run using the in-house developed program. Average differences from the base case [in %] are as follows:

Trips/hour : 2.25 %,
Production/op. hour : 3.40 %,
Fuel consumption [l/cycle] : 2.20 %,
Fuel consumption [l/t] : 2.32 %.

2. **Time study**

The data from time studies from various mines were also summarized. Only time studies from the Highvale mine provided enough data to be reliable. These collected data were evaluated and means were calculated. Data from field time studies were also compared with data supplied by Kress

company, because Kress company haulers were surveyed in the field. Data were adjusted to reflect the higher velocities of the trucks in real conditions as opposed to the "recommended" values supplied by the manufacturer. The TKPH limitation was removed. Data calculated by the in-house developed computer model, the so called base case, were obtained by limiting the velocities to the maximum haulage speed at the mine and were quite comparable to the surveyed values. Data obtained from this comparison study were evaluated and extreme values explained. A 10 % difference between time study data and data calculated in the base case was considered acceptable for the validation purposes.

3. Critiques from users

The truck and shovel computer program was distributed to three mining companies for their evaluation. Presentation of the model and information on use of the model was given and the potential users were asked to provide an evaluation report which describes the applications and evaluation of the model. In general, initial response was very favourable. Any practical comments, or requests from the users, were incorporated in the model. Some requests are under review at present and will be included in the model if the review supports the need.

The critiques of the model from the users also provided us with the opportunity to see the future application of the model and to identify needs as envisaged by the mining companies. The projects to measure rolling resistance, incorporate other loading equipment into the model, extend the model to provide 'event-based' simulation, update the model to be able to accept and use data collected from installation of truck management systems, transfer the model on IBM PC compatible hardware, and use the digitizer to enter data from mine plan to the model, were initiated jointly with industry as a direct result of the users suggestions.

It is envisaged, that validation and modification of the computer model of truck and shovel operation will continue. Such model development will be heavily influenced by industry needs and priorities.

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